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ORIGINAL PAPER

Influence of Bolus Consistency and Position on Esophageal High-Resolution Manometry Findings

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Abstract *Background* Conventional esophageal manometry evaluating liquid swallows in the recumbent position measures pressure changes at a limited number of sites and does not assess motility during solid swallows in the physiologic upright position. *Aim* To evaluate esophageal motility abnormalities during water and bread swallows in the upright and recumbent positions using high-resolution manometry (HRM). *Methods* Thirty-two-channel HRM testing was performed using water (10 ml each) and bread swallows in the upright and recumbent positions. The swallows were considered normal if the distal peristaltic segment >30 mmHg was >5 cm, ineffective if the 30-mmHg pressure band was <5 cm, and simultaneous if the onset velocity of the 30 mmHg pressure band was >8 cm/s. Abnormal esophageal manometry was defined as the presence of ≥30% ineffective and/or ≥20% simultaneous contractions. *Results* The data from 96 patients (48 F; mean age 51 years, range 17–79) evaluated for dysphagia (56%), chest pain (22%), and gastroesophageal reflux disease (GERD) symptoms (22%) were reviewed. During recumbent water swallows, patients with dysphagia, chest pain, and GERD had a similar prevalence of motility abnormalities. During upright bread swallows, motility abnormalities were more frequent ($p = 0.01$) in patients with chest pain (71%) and GERD (67%) compared to patients with dysphagia (37%). *Conclusions* Evaluating bread swallows in the upright position reveals differences in motility abnormalities overlooked by liquid swallows alone.

Keywords High-resolution manometry · Dysphagia · Chest pain · Gastroesophageal reflux disease

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Introduction

Esophageal manometry has been used for more than 40 years to diagnose esophageal motility abnormalities [1]. Manometry provides information on the amplitude and coordination of esophageal contractions and the resting and residual pressures of the upper and lower esophageal sphincter. After excluding structural lesions, patients with dysphagia and/or non-cardiac chest pain are referred for esophageal motility testing with the question as to whether these symptoms are associated with esophageal motility abnormalities [2]. Other indications for manometry include evaluating the presence of motility abnormalities prior to fundoplication and to assist with the location of the lower esophageal sphincter (LES) prior to esophageal reflux monitoring [3].

Patients with esophageal motility abnormalities have symptoms during the ingestion of both liquids and solids. Usually, deglutition occurs almost exclusively in the upright position. Therefore, it seems more reasonable to evaluate esophageal symptoms during the swallowing of liquid and solid substances in the more physiologic upright position. Following the report of Sears et al. [4], other investigators have evaluated esophageal manometry in the upright and supine body positions for liquid and solid swallows in healthy volunteers [5, 6]. Howard et al. [7], comparing the results of esophageal manometry during water swallows and eating bread, found substantial differences in esophageal motility during water swallows as compared to eating. Evaluating the patterns of esophageal motility in diabetic patients with previously documented delayed esophageal emptying, Holloway et al. [8] noticed peristaltic failure leading to transit hold-up more frequently during solid than liquid swallows. Still, there are limited esophageal manometry data during standard solid swallows in patients with dysphagia and chest pain [9].

Conventional esophageal manometry is performed in the supine position and evaluates esophageal peristalsis using 5–10 ml water swallows [10]. Taking advantage of technological advances and increasing computing power, newer systems use 32–36 manometry channels (high-resolution manometry; HRM). The higher density of pressure channels (i.e., every 1–1.5 cm) allows the monitoring of the activities of the upper esophageal sphincter, esophageal body, lower esophageal sphincter, and proximal stomach during the same swallow, without having to perform additional adjustments for various esophageal lengths (usually ranging from 21 to 25 cm [11]). Two-dimensional spatio-temporal plots provide a more appealing representation of the pressure changes and allow a better characterization of the pressure profiles at the gastroesophageal junction [12].

The aim of the present study was to compare findings of esophageal motility abnormalities during water and bread swallows in the upright and recumbent (left lateral decubitus) positions in patients with dysphagia, chest pain, and gastroesophageal reflux disease (GERD) symptoms using high-resolution manometry.

Methods

For this analysis, we reviewed the collected data from symptom questionnaires and high-resolution manometry tracings recorded between April 2003 and November 2005. Patients were referred to our tertiary care center (University Hospital of Zurich) for the evaluation of esophageal symptoms. The Ethics Committee of the University Hospital of Zurich approved the retrospective data analysis.

Patients and symptom data

Patients were asked to come to the laboratory after at least 4 h of fasting. Prior to esophageal manometry, patients were asked to complete a questionnaire, which included data on the frequency and intensity of heartburn, chest pain, regurgitation, and dysphagia. For heartburn and chest pain, patients were asked to rate the frequency on a five-point scale (never, less than once a week, once every 3 days, once every 2 days, daily), the number of episodes on a six-point scale (never, once a day, twice a day, three times a day, four times a day, more than 4 times a day), the duration of the episode on a seven-point scale (none, 1 min, 1–5 min, 5–10 min, 10–30 min, 30–60 min, more than 60 min), and the intensity of episodes on a six-point scale (none, very mild, mild, middle, strong, very strong). For regurgitation, patients were asked to rate the frequency, the number of episodes, and also the intensity of the complaints on the same scales as described above. For dysphagia, patients were asked to rate the frequency and the intensity as described above. For each symptom, composite scores were computed according to the Eraflux questionnaire [13]. In patients with multiple symptoms, the symptom with the highest score was considered as the primary symptom.

Manometry system

We used a multiple-use water-perfused HRM silicone micrometric catheter (4-mm external diameter) with 32 channels (Dentsleeve, Wayville, South Australia, Australia) spaced helically along the catheter. The distance between the first and second channel was 5 cm. Channels 2–10 and 25–32 were 1 cm apart, while channels 11–24 were 1.3 cm apart. The catheter was perfused with distilled water using a pneumatically activated manometric pump designed and built by G.S. Hebbard. Each channel was connected to an external transducer (Abbott Transpac IV, Abbott Laboratories, Ontario, Canada). The analog signals were amplified and transformed into digital signals. Manometric data from each channel was stored and analyzed by the Trace! v1.2 software system (Trace! v1.2 videomanometry system, G.S. Hebbard, Royal Melbourne Hospital, Melbourne, Australia) using the spatio-temporal plot representation [10].

High-resolution manometry data acquiring and analysis protocol

Prior to the insertion of the high-resolution manometry (HRM) catheter, one nostril was anesthetized using lidocaine 2%. The 32-channel water-perfused HRM catheter was passed transnasally through the esophagus into the stomach. The catheter was positioned such that the distal channels located 1 cm apart spanned the lower esophageal sphincter (LES). Patients were then given ten water swallows (10 ml each) and ten bread swallows (small pieces $2 \times 2 \times 2$ cm^3) in the upright and recumbent (left lateral

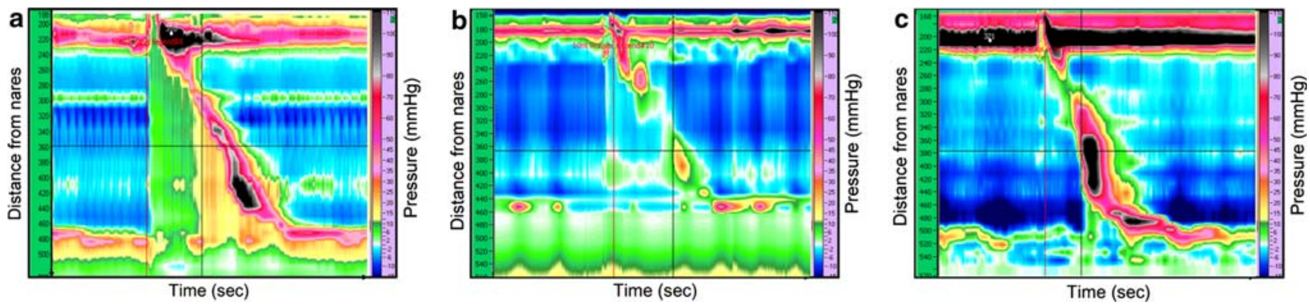


Fig. 1 Examples of normal (**a**), ineffective (**b**), and simultaneous (**c**) contractions during a 10 ml water swallow on a 32-channel high-resolution manometry (HRM) tracing. HRM spatio-temporal plot depicts the direction and force of pressure activity in the esophagus from the pharynx to the stomach. Time is on the *x* axis and distance from the nares is on the *y* axis. Each pressure is assigned a color (legend on the right)

decubitus) positions, 20–30 s apart. Double swallows and swallows containing cough-induced pressure artifacts were excluded from the analysis.

The lower esophageal sphincter resting pressure (LESP) was measured in the upright and recumbent positions prior to each set of water and bread swallows. The LESP was calculated as the average mid-respiratory distal pressure band corresponding to the LES.

The contraction amplitude of esophageal contractions was referenced to the gastric baseline. For swallows in the upright position, the software used a hydrostatic pressure correction. Swallows were considered as: (1) normal if, in the isocontour plot representation, a peristaltic band >30 mmHg spanned over at least 5 cm in the distal esophagus; (2) ineffective if the pressure band >30 mmHg in the distal esophagus was less than 5 cm or the pressure in the distal esophagus did not exceed 30 mmHg; and (3) simultaneous if the onset velocity of the pressure band >30 mmHg exceeded 8 cm/s in the distal esophagus (Fig. 1). Using HRM representation, the distal esophagus was defined as the section of the esophagus spanning from the physiologic pressure through to the proximal LES border.

Esophageal contractions were also evaluated using conventional manometric criteria by analyzing pressure measurements only at 3 cm and 8 cm above the LES. Swallows were considered as: (1) normal if the contraction amplitude at 3 cm and 8 cm above the LES exceeded 30 mmHg and the onset velocity was less than or equal to 8 cm/s; (2) ineffective if the contraction amplitude at 3 cm or 8 cm above the LES was <30 mmHg; and (3) simultaneous if the contraction amplitude at 3 cm and 8 cm above the LES exceeded 30 mmHg and the onset velocity exceeded 8 cm/s.

We defined ineffective esophageal motility (IEM) by the presence of 30% or more ineffective swallows and distal esophageal spasm (DES) by the presence of 20% or more simultaneous contractions [14]. Datasets with less than five usable water swallows in the recumbent position were excluded, as were the data from patients with achalasia.

Statistics

Descriptive statistics were used to analyze the characteristics of patients presenting with dysphagia, chest pain, and GERD symptoms. We determined the percentage of normal, ineffective, and simultaneous swallows in each patient, and then, an average for each group was calculated. Comparisons between proportions were made using the Chi-square or Fisher-exact tests, depending on the number of observations. Parametric or non-parametric tests were used to compare continuous variables according to the normality of the data distribution. Kappa statistics were used to evaluate the agreement between manometric findings identified using conventional manometry and HRM criteria. A *p*-value less than 0.05 was considered as statistically significant.

Results

Between April 2003 and November 2005, 225 HRM examinations were performed with clinical and research indications. Data from 96 patients (48 females, mean age 51 years, range 17–79 years) had at least five interpretable water swallows in the recumbent position and were included in the analysis. The main symptom in 54 (56%) patients was dysphagia, in 21 (22%) chest pain, and in 21 (22%) heartburn and/or regurgitation (i.e., GERD symptoms). There was no difference in the gender distribution in the group of patients with dysphagia, chest pain, and GERD. Patients with GERD symptoms were significantly ($p < 0.05$) younger (mean ± SEM = 42 ± 3 years) than patients presenting with dysphagia (53 ± 2 years) or chest pain (57 ± 4 years).

Influence of bolus consistency and position on manometric findings

The group of 96 patients had an average of 81% normal, 15% ineffective, and 4% simultaneous contractions during water swallows in the recumbent position and an average of 68% normal, 28% ineffective, and 4% simultaneous contractions during water swallows in the upright position. During bread swallows in the recumbent position, an average of 66% of contractions were manometrically normal, 25% ineffective, and 9% simultaneous. During bread swallows in the upright position, patients had an average of 61% normal, 32% ineffective, and 7% simultaneous contractions. Evaluating data in all 96 patients, we found that differences between percentages of normal, ineffective, and simultaneous swallows were not statistically significant (ANOVA $p > 0.05$).

Average percentage of normal, simultaneous, and ineffective swallows stratified by bolus consistency, position, and primary symptom

In the recumbent position, patients with dysphagia, chest pain, and GERD symptoms had similar percentages of manometrically normal contractions during water swallows. There was also no difference in the percentage of manometrically normal contractions between patients with dysphagia, chest pain, and GERD symptoms during water swallowing in the upright position and bread swallows in the upright or recumbent positions. The same was noticed for the percentage of manometrically ineffective and simultaneous contractions. The average percentages of normal, ineffective, and simultaneous contractions are presented in Fig. 2.

Manometric findings in the upright and recumbent positions during water and bread swallows

There was a significant difference (Chi-square 15.6, df = 6, $p < 0.05$) between the proportion of patients with normal manometry during water swallows recumbent (74%), water swallows upright (60%), bread recumbent (58%), and bread upright (49%). The percentages of patients with normal manometry, IEM, and DES in the upright and recumbent positions during water and bread swallows are shown in Fig. 3.

Manometric differences between patients with dysphagia, chest pain, and GERD symptoms

The lower esophageal sphincter resting pressure (LESP) in the upright position was similar ($p = 0.61$) in patients with dysphagia (11.1 ± 0.9 mmHg), chest pain (11.7 ± 0.8 mmHg), and GERD symptoms (10.2 ± 1.4 mmHg). In the recumbent position, we noticed also no difference ($p = 0.71$) in the LESP of patients with dysphagia (18.0 ± 1.4 mmHg), chest pain (20.1 ± 1.1 mmHg), and GERD symptoms (17.8 ± 2.1 mmHg). The LESP was significantly higher ($p < 0.01$) in the recumbent position compared to the upright position in each of the three groups, as previously shown [4].

During water swallows in the recumbent and upright positions, the same proportions of patients had normal manometry, regardless of their main symptom. During bread swallows in the recumbent position, 64% of patients with dysphagia, 38% of patients with chest pain, and 62% of patients with GERD symptoms had normal manometry ($p = 0.07$). During bread swallows in the upright position, the proportion of patients with dysphagia and normal manometry (63%) was significantly higher ($p = 0.01$) than the proportion of patients with chest pain and GERD having normal manometry (29% and 33%, respectively).

In the group of patients with dysphagia, there was no difference in the proportion of patients with normal manometry during water or bread swallows in the recumbent or upright positions. In the group of patients whose main complaint was chest pain, the proportion of normal manometry decreased from 71% during water swallows in the recumbent position to 52% during water swallows upright, 38% during bread swallows recumbent, all the way to 29% during bread swallows in the upright position. These differences, though, did not reach statistical significance. Similar, non-significant differences were observed in the group of patients presenting primarily with GERD symptoms. These data are summarized in Table 1.

Agreement between manometric findings using HRM and conventional manometry criteria

When comparing manometric findings using HRM and conventional manometry criteria, we found an excellent agreement ($\kappa = 0.9$) between these assessments during water swallows in the recumbent position. The only disagreement was noticed in four patients who fulfilled IEM criteria by conventional manometry, but were considered normal by HRM. The agreement between conventional manometry and HRM findings was also very good during water swallows in the upright position ($\kappa = 0.85$) and bread swallows in the recumbent ($\kappa = 0.82$) and upright ($\kappa = 0.79$) positions.

Discussion

In the present study, we report the high-resolution manometry (HRM) findings during water and bread

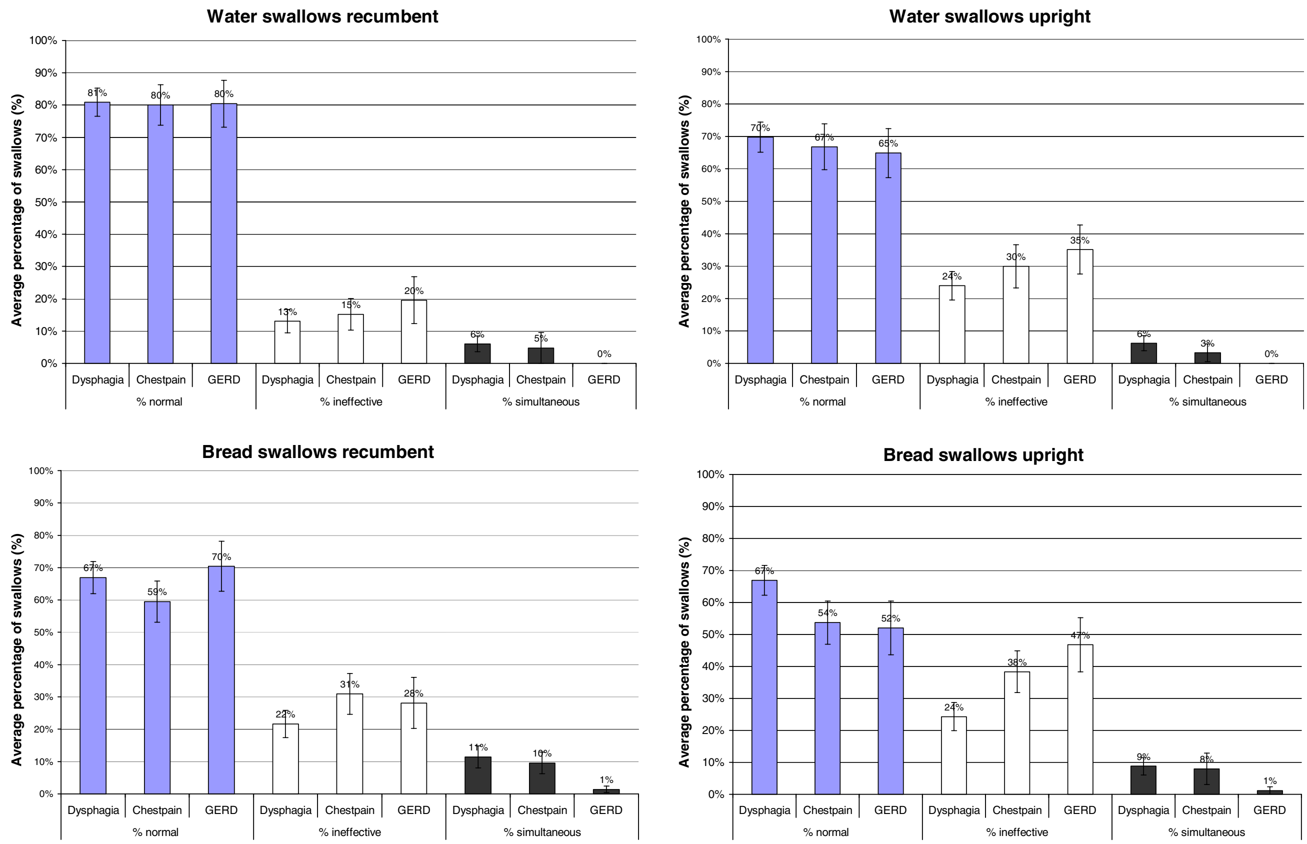
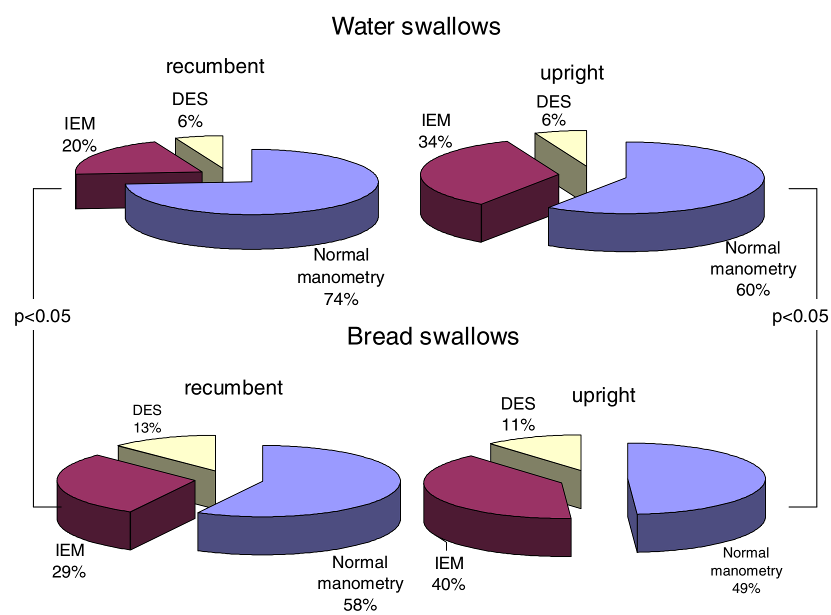


Fig. 2 Percentage of manometric normal, ineffective, and simultaneous contractions in patients with dysphagia, chest pain, and gastroesophageal reflux disease (GERD) symptoms during water and bread swallows in the upright and recumbent positions. The data are presented as mean ± SEM

Fig. 3 Percentage of patients with normal manometry, distal esophageal spasm (DES), and ineffective esophageal motility (IEM) during water and bread swallows in the recumbent and upright positions



swallows in the upright and recumbent positions in patients with dysphagia, chest pain, and GERD symptoms. We noticed more patients having manometric abnormalities during bread swallows in the upright position than during water swallows when either upright or recumbent. In addition, bread swallows in the upright position revealed a

Table 1 Number and percentage of patients with normal manometry, IEM, and DES separated by the main symptom (dysphagia, chest pain, and GERD)

	Dysphagia (N = 54)			Chest pain (N = 21)			GERD (N = 21)			p-value
	Normal	IEM	DES	Normal	IEM	DES	Normal	IEM	DES	
Water recumbent	40	9	5	15	5	1	16	5	0	0.59
	74%	17%	9%	71%	24%	5%	76%	24%	0%	
Water upright	36	13	5	11	9	1	10	11	0	0.116
	67%	24%	9%	52%	43%	5%	48%	52%	0%	
Bread recumbent	34	11	8	8	9	4	13	8	0	0.072
	64%	21%	15%	38%	43%	19%	62%	38%	0%	
Bread upright	34	13	7	6	12	3	7	13	1	0.009
	63%	24%	13%	29%	57%	14%	33%	62%	5%	

p-value: Chi square test comparing proportions of normal manometry, IEM, and DES between groups of patients with dysphagia, chest pain, and GERD symptoms

higher proportion of manometric abnormalities in patients with chest pain and GERD symptoms compared to those with dysphagia. These differences were not obvious during water swallows in the recumbent position.

High-resolution manometry (HRM) provides additional information on esophageal peristalsis. In contrast to conventional manometry with measuring points 5 cm apart, HRM pressure profiles were generated based on data from closely spaced measurement sites. Thus, it provides more detailed information on the peristaltic front, including the proximal portion, the physiologic pressure trough, and the distal component of the esophageal peristalsis [15]. To date, Ghosh et al. [16] reported normal values for high-resolution manometry based on measurements obtained in 75 healthy volunteers. While providing a very detailed analysis of individual pressure segments within the esophagus, this report fails to report HRM diagnostic criteria for normal, ineffective, and simultaneous contractions. Therefore, the approach to analyze HRM tracings used in the present study was based on previously published experiences focusing primarily on the distal part of the isocontour plot. Combined impedance-manometry studies evaluating bolus transit in patients with ineffective esophageal motility revealed that the majority (i.e., 87–94%) of contractions exceeding 30 mmHg at two distinct (5 cm apart) sites in the distal esophagus had complete bolus transit [17]. Therefore, we requested the peristaltic pressure band to span at least 5 cm in the distal esophagus in order to consider the swallow to be manometrically normal. The excellent agreement between HRM and conventional manometry findings could provide an argument for using the proposed criteria to evaluate esophageal peristalsis using high-resolution manometry. On the other hand, one might question the need for high-resolution manometry, given the good agreement with conventional criteria to diagnose esophageal motility abnormalities.

For the overall evaluation of the study, we used the manometric definitions for normal manometry, ineffective esophageal motility (IEM), and distal esophageal spasm (DES) proposed by Spechler and Castell [14], understanding that these criteria were proposed for the interpretation of conventional manometry data during water swallows in the recumbent position. It is important to be aware of this fact, since studies evaluating peristaltic activity during bread swallows report a higher frequency of non-peristaltic contractions during bread swallows compared to water swallows [18]. Still, since the aim of our study was to compare manometric abnormalities in patients with dysphagia, chest pain, and GERD symptoms, we decided to use the same diagnostic criteria for bread swallows (upright and recumbent) and water swallows in the upright position in order to have a simplified and consistent interpretation.

As mentioned in the introduction, Sears et al. [4] evaluated the effects of position and bolus consistency on esophageal motility in a group of 15 healthy subjects. In this group of volunteers, the investigators evaluated the distal esophageal peristalsis during six liquid swallows in the upright and supine positions, and six solid (small marshmallow) swallows in the upright position. Atypical wave forms (non-transmitted, simultaneous, and repetitive contractions) were noted more frequently during the upright position compared to the supine position ($p < 0.01$) and during solid versus liquid swallows ($p < 0.05$). Therefore, our findings of a higher percentage of manometric abnormalities during bread swallows in the upright position in patients are consistent with the observations by Sears et al.

Allen et al. [9] evaluated the results of esophageal manometry during water swallows in the recumbent position and food ingestion in the upright position in 100 patients reporting dysphagia (77) and chest pain (60). Each patient received ten 5 ml water swallows 30 s apart during standard manometry and had to ingest a meal consisting of beef tips, bread, jello, and water ad libitum. Patients were asked to rate their symptoms during water swallows and meal ingestion. A motility abnormality was considered symptomatic if patients reported chest pain or dysphagia within 10 s from the time that the abnormality occurred. The authors noted a higher proportion ($p < 0.01$) of patients reporting dysphagia during the ingestion of the meal (43%) than during standard manometry (8%). Chest pain episodes were reported with a similar, rare frequency during food ingestion and standard manometry (5%). Based on these findings, the authors concluded that food ingestion should be used as a provocative test in patients with non-obstructive dysphagia.

The finding of a higher proportion of esophageal motility abnormalities during bread swallows in patients with chest pain and GERD symptoms compared to patients with dysphagia requires further evaluations. Although our study does not include data from normal volunteers, which would allow us to understand to what extent the percentages of abnormal peristaltic responses noticed in patients with chest pain, dysphagia, and reflux symptoms differ from normal, the fact that there are differences between these groups is of interest. The interpretation of these findings is even more difficult in the absence of normal HRM data for bread swallows and the observation by Pouderoux et al. [19] during combined videofluoroscopy and manometry, indicating that bread is rarely cleared from the esophagus with a single swallow. Noticing low-amplitude contractions distal to the stopping point of the bolus, Pouderoux et al. [19] interpreted this phenomenon as the result rather than the cause of solid bolus retention. Still, the differences noted in our study were observed while analyzing the tracings from patients with chest pain, dysphagia, and GERD symptoms using the same criteria. Therefore, understanding whether they are the cause or effect of bolus retention becomes secondary to understanding why different motility patterns during bread swallows are observed in patients with dysphagia, chest pain, and GERD symptoms.

A further intriguing observation is the increased percentage of abnormal peristaltic responses in patients with chest pain and GERD symptoms compared to patients with dysphagia. Based on our data, we can only speculate on the meaning of these, at first look, counter-intuitive findings. One possible explanation could be that a certain contractility and peristaltic response is important in the pathogenesis of dysphagia, whereas chest pain could result from the passive distension of the esophagus in the absence of an effective peristalsis. The well-known increased frequency of ineffective esophageal contractions in patients with GERD remains an enigma as to what extent it contributes or is the result of the abnormal distal esophageal acid exposure.

In conclusion, the present study suggests that high-resolution manometry using water and bread swallows identifies subtle differences between patients with chest pain, dysphagia, and GERD symptoms overlooked by recumbent water swallows alone. The next steps are now to better understand the differences in esophageal motility between different groups of patients and to evaluate the clinical meaning of the additional information provided by bread swallows, understanding that motility abnormalities during bread swallows can also be noted in healthy volunteers. Whether or not bread swallows will become an integral part of routine esophageal manometry depends mainly on the outcome data.

References

1. Nagler R, Spiro HM (1960) Esophageal motility studies in the clinical diagnosis of esophageal disease. Conn Med 24:1–7
2. Murray JA, Clouse RE, Conklin JL (2003) Components of the standard oesophageal manometry. Neurogastroenterol Motil 15:591–606
3. Pandolfino JE, Kahrilas PJ (2005) AGA technical review on the clinical use of esophageal manometry. Gastroenterology 128:209–224
4. Sears VW Jr, Castell JA, Castell DO (1990) Comparison of effects of upright versus supine body position and liquid versus solid bolus on esophageal pressures in normal humans. Dig Dis Sci 35:857–864
5. Kaye MD, Wexler RM (1981) Alteration of esophageal peristalsis by body position. Dig Dis Sci 26:897–901
6. Tutuian R, Elton JP, Castell DO, Gideon RM, Castell JA, Katz PO (2003) Effects of position on oesophageal function: studies using combined manometry and multichannel intraluminal impedance. Neurogastroenterol Motil 15:63–67
7. Howard PJ, Maher L, Pryde A, Heading RC (1991) Systematic comparison of conventional oesophageal manometry with oesophageal motility while eating bread. Gut 32:1264–1269
8. Holloway RH, Tippett MD, Horowitz M, Maddox AF, Moten J, Russo A (1999) Relationship between esophageal motility and transit in patients with type I diabetes mellitus. Am J Gastroenterol 94:3150–3157
9. Allen ML, Orr WC, Mellow MH, Robinson MG (1988) Water swallows versus food ingestion as manometric tests for esophageal dysfunction. Gastroenterology 95:831–833
10. Freeman J, Hila A, Castell DO (2004) Esophageal manometry. In: Castell DO, Richter JE (eds) The esophagus, 4th edn. Lippincott Williams & Wilkins, New York, pp 115–134
11. Meyer GW, Gernhardt DC, Castell DO (2000) Peristaltic pressure profiles of the human esophagus. J Clin Gastroenterol 30:270–273
12. Fox M, Hebbard GS, Janiak P, Brasseur JG, Ghosh S, Thumshirn M, Fried M, Schwizer W (2004) High-resolution manometry predicts the success of oesophageal bolus transport and identifies clinically important abnormalities not detected by conventional manometry. Neurogastroenterol Motil 16:533–542
13. Schwizer W, Thumshirn M, Dent J, Guldenschuh I, Menne D, Cathomas G, Fried M (2001) Helicobacter pylori and symptomatic relapse of gastro-oesophageal reflux disease: a randomised controlled trial. Lancet 357:1738–1742

14. Spechler SJ, Castell DO (2001) Classification of oesophageal motility abnormalities. Gut 49:145–151
15. Ghosh SK, Janiak P, Schwizer W, Hebbard GS, Brasseur JG (2006) Physiology of the esophageal pressure transition zone: separate contraction waves above and below. Am J Physiol Gastrointest Liver Physiol 290:G568–G576
16. Ghosh SK, Pandolfino JE, Zhang Q, Jarosz A, Shah N, Kahrilas PJ (2006) Quantifying esophageal peristalsis with high-resolution manometry: a study of 75 asymptomatic volunteers. Am J Physiol Gastrointest Liver Physiol 290:G988–G997
17. Tutuian R, Castell DO (2004) Clarification of the esophageal function defect in patients with manometric ineffective esophageal motility: studies using combined impedance-manometry. Clin Gastroenterol Hepatol 2:230–236
18. Johnston BT, Collins JS, McFarland RJ, Blackwell JN, Love AH (1993) A comparison of esophageal motility in response to bread swallows and water swallows. Am J Gastroenterol 88:351–355
19. Pouderoux P, Shi G, Tatum RP, Kahrilas PJ (1999) Esophageal solid bolus transit: studies using concurrent videofluoroscopy and manometry. Am J Gastroenterol 94:1457–1463